3.7 User Defined Functional Form For Material Properties

An addition to this version of **MAC/GMC** is the option for a user to implement functionally dependent material properties. With this the elastic and/or inelastic material properties may be defined as a function of any variable contained in SA and DSA (e.g., stress, strain, time, temperature, etc.) In certain cases, the user must also provide code for determining the stiffness matrix (USRFORMDE) or the time derivative of the stiffness matrix (USRCPEVAL). This is accomplished by using the subroutines **USRFUN, USRFORMDE, and USRCPEVAL** into which the user writes the necessary FORTRAN code for the particular constitutive model being implemented. All three routines are shown below.

```
c######################################################################
       SUBROUTINE USRFUN(MN, TIME, TSTEP, CTEMP, DTEMPR, SA, DSA,
     &     DOLD, PEM, PVM, D, LOCTISO, ALPA, ALPT,
     &     NE, NV, NMTS, NEP, NVP, NSASIZE)

c     purpose:  user subroutine to allow elastic and viscoplastic
c               material properties to be functions of TEMP or
c               field variables.  Used for user defined functional
c               form material properties, that is, when:
c               (mat .eq. 'U') .and. (ifm .eq. 2)
c
c     note:     can be used in conjunction with a provided material
c               constitutive model, or a constitutive model input
c               by the user in USRMAT

      INCLUDE 'parm.inc'
      IMPLICIT DOUBLE PRECISION (A - H, O - Z)
      DIMENSION DOLD(6, 6), D(3)
      DIMENSION PEM(NEP, NMTS), PVM(NVP, NMTS)
      DIMENSION ALPA(NMTS), ALPT(NMTS)
      DIMENSION DSA(NSASIZE), SA(NSASIZE)
**********************************************************************
c  note: 1) in this subroutine, [SA] and [DSA] contain the
c           micro (subcell) quantities for aboudi's micromechanics model
c
c        2) arrangement of [dsa] & [sa]  arrays:
c           variable             location
c         +-------------------------------------------------------
c         | strain rate          (1-6)  (contains ENGINEERING shears)
c         |-------------------------------------------------------
c         | stress rate          (7-12)
c         |-------------------------------------------------------
c         | inelastic
c         | strain rate          (13-18)  (contains ENGINEERING shears)
c         |-------------------------------------------------------
c         | 12 "slots"           (19-30)
c         | for state variables
c         |-------------------------------------------------------
c         | thermal strain rate  (31-36)
c         +-------------------------------------------------------
```

```
************************************************************************
c NOTE:  quantities in [SA] and [DSA] are SUBCELL quantities - the
c        values on entry are for the first subcell containing material
c        # MN - the values on exit of this subroutine will be applied to
c        ALL SUBCELLS containing material # MN.  It is thus recommended
c        that, if using the field variables, you assign the appropriate
c        material # to ONE SUBCELL ONLY.  Use of [SA] and [DSA] in this
c        context in conjunction with bending in laminate theory will
c        result in erroneous results as field variables become dependent
c        on through-thickness position.
************************************************************************
c   on entry:
c      MN           - material number
c      TIME         - current time
c      TSTEP        - current time step
c      CTEMP        - current temperature
c      DTEMPR       - time rate of change of temperature
c      SA           - vector of total (integrated) quantities (see above)
c      DSA          - vector of rate quantities (see above)
c      DOLD(6, 6)   - previous elastic material stiffness matrix
c      PEM(NE, MN) - vector of previous elastic constants for material
c                     # MN (where NE = # of elastic constants --> 9 MAX)
c      PVM(NV, MN) - vector of previous viscoplastic constants for
c                     material # MN
c                     (where NV = # of viscoplastic constants --> 19 MAX)
c
c   expected on exit:
c      PEM(NE, MN) - vector of current elastic constants for material MN
c      PVM(NV, MN) - vector of current viscoplastic constants for
c                     material MN
c      D(3)         - vector of direction cosines
c                     (required for models 3, 7, & 9)
c      LOCTISO      - flag indicating if ANY material exhibits
c                     local transverse isotropy (and global anisotropy)
c                   = 0 - all materials are at most globally transversely
c                         isotropic (D not used)
c                   = 1 - at least one material is locally transversely
c                         isotropic (D used)
c      ALPA(MN)     - longitudinal cte for material MN
c      ALPT(MN)     - transverse cte for material MN
************************************************************************

************************************************************************
*                        BEGIN USER EDITS                              *
************************************************************************
c                          place code here
************************************************************************
*                         END USER EDITS                               *
************************************************************************
      RETURN
      END
```

```
      SUBROUTINE USRFORMDE(MN, PEM, PVM, D, LOCTISO, DNEW,
     &     NE, NV, NEP, NVP, NMTS)

c     purpose:  user subroutine to allow formation of material stiffness
c               matrices based on a user constitutive model (used when
c               ncmd = 99)
c
C      INCLUDE 'parm.inc'

      IMPLICIT DOUBLE PRECISION (A - H, O - Z)

      DIMENSION DNEW(6, 6)
      DIMENSION PEM(NEP, NMTS), PVM(NVP, NMTS)
      DIMENSION D(3)

************************************************************************
c   on entry:
c      MN          - material number
c      PEM(NE, MN) - vector of elastic constants for material
c                    # MN (where NE = # of elastic constants --> 9 MAX)
c      PVM(NV, MN) - vector of viscoplastic constants for material # MN
c                    (where NV = # of viscoplastic constants --> 19 MAX)
c      D(3)        - vector of direction cosines
c                   (required for models 3, 7, & 9)
c      LOCTISO     - flag indicating if ANY material exhibits
c                    local transverse isotropy (and global anisotropy)
c                  = 0 - all materials are at most globally transversely
c                        isotropic (D not used)
c                  = 1 - at least one material is locally transversely
c                        isotropic (D used)
c
c   expected on exit:
c      DNEW(6, 6)  - current elastic material stiffness matrix

************************************************************************
*                       BEGIN USER EDITS                               *
************************************************************************
c                              place code here
************************************************************************
*                        END USER EDITS                                *
************************************************************************

      RETURN
      END
```

```
#########################################################################
      SUBROUTINE USRCPEVAL(DSA, SA, MN, TIME, TSTEP, CTEMP, DTEMPR,
     &     DNEW, DOLD, PEM, PVM, D, LOCTISO, ALPA, ALPT, DDOT,
     &     NE, NV, NMTS, NEP, NVP, NSASIZE)


c     purpose:  user subroutine to allow formation of the TIME
c               derivative of the material stiffness matrix.
c               this subroutine is used when:
c               a) material properties are user defined and functional
c                  form.  That is:  (mat .eq. 'U') .and. (ifm .eq. 2)
c               b) the constitutive model is user-defined, and the
c                  material properties are not functional form, and
c                  the material properties are temperature-dependent
c                  that is: (ncmd .eq. 99) .and. (ifm .ne. 2) .and.
c                  (ndpt .eq. 2)

      IMPLICIT DOUBLE PRECISION (A - H, O - Z)

      DIMENSION DNEW(6, 6), DOLD(6, 6)
      DIMENSION DDOT(6, 6)

      DIMENSION PEM(NEP, NMTS), PVM(NVP, NMTS)
      DIMENSION ALPA(NMTS), ALPT(NMTS)
      DIMENSION DSA(NSASIZE), SA(NSASIZE)

**************************************************************************
c  note: 1) in this subroutine, [SA] and [DSA] contain the
c           micro (subcell) quantities for aboudi's micromechanics model
c
c        2) arrangement of [dsa] & [sa]  arrays:
c           variable             location
c         +-------------------------------------------------------------
c         | strain rate          (1-6)  (contains ENGINEERING shears)
c         |-------------------------------------------------------------
c         | stress rate          (7-12)
c         |-------------------------------------------------------------
c         | inelastic
c         | strain rate          (13-18)  (contains ENGINEERING shears)
c         |-------------------------------------------------------------
c         | 12 "slots"           (19-30)
c         | for state variables
c         |-------------------------------------------------------------
c         | thermal strain rate  (31-36)
c         +-------------------------------------------------------------
**************************************************************************
c NOTE:  quantities in [SA] and [DSA] are SUBCELL quantities - the
c        values on entry are for the first subcell containing material
c        # MN - the values on exit of this subroutine will be applied to
c        ALL SUBCELLS containing material # MN.  It is thus recommended
c        that, if using the field variables, you assign the appropriate
c        material # to ONE SUBCELL ONLY.  Use of [SA] and [DSA] in this
c        context in conjunction with bending in laminate theory will
c        result in erroneous results as field variables become dependent
c        on through-thickness position.
```

```
************************************************************************
c   on entry:
c      SA          - vector of total (integrated) quantities (see above)
c      DSA         - vector of rate quantities (see above)
c      MN          - material number
c      TIME        - current time
c      TSTEP       - current time step
c      CTEMP       - current temperature
c      DTEMPR      - time rate of change of temperature
c      DNEW(6, 6)  - current elastic material stiffness matrix
c      DOLD(6, 6)  - previous elastic material stiffness matrix
c      PEM(NE, MN) - vector of current elastic constants for material MN
c                    (where NE = # of elastic constants --> 9 MAX)
c      PVM(NV, MN) - vector of current viscoplastic constants for
c                    material MN
c                    (where NV = # of elastic constants --> 19 MAX)
c      D(3)        - vector of direction cosines
c                    (required for models 3, 7, & 9)
c      LOCTISO     - flag indicating if ANY material exhibits
c                    local transverse isotropy (and global anisotropy)
c                   = 0 - all materials are at most globally transversely
c                         isotropic (D not used)
c                   = 1 - at least one material is locally transversely
c                         isotropic (D used)
c      ALPA(MN)    - longitudinal cte for material MN
c      ALPT(MN)    - transverse cte for material MN
c
c   expected on exit:
c      DDOT(6, 6)  - derivative with respect to TIME of stiffness matrix
************************************************************************
************************************************************************
*                      BEGIN USER EDITS                                *
************************************************************************
c                          place code here
************************************************************************
*                       END USER EDITS                                 *
************************************************************************

      RETURN
      END
```

A description of the input and output required for each subroutine is given in the comment statements at the top of each subroutine.

☞ **Note: MAC/GMC** assumes the longitudinal direction for the material is oriented in the x_1- coordinate direction, see Fig. 6.

☞ **Note: Example K** illustrates how one could use each of these routines to define material properties as well as the associated elastic stiffness matrix.